ABNORMAL HIGH SITUATION OF NEGATIVE CHARGE DISAPPEARING FROM THUNDERCLOUD BY A LIGHTNING

BY

Yuichi TAMURA

Since 1957, the thunderstorm electric field at the ground level had been observed by a network which consisted of eight stations distributed around Kyoto City. The distribution of the stations is shown in Fig. 1. The observing instrument

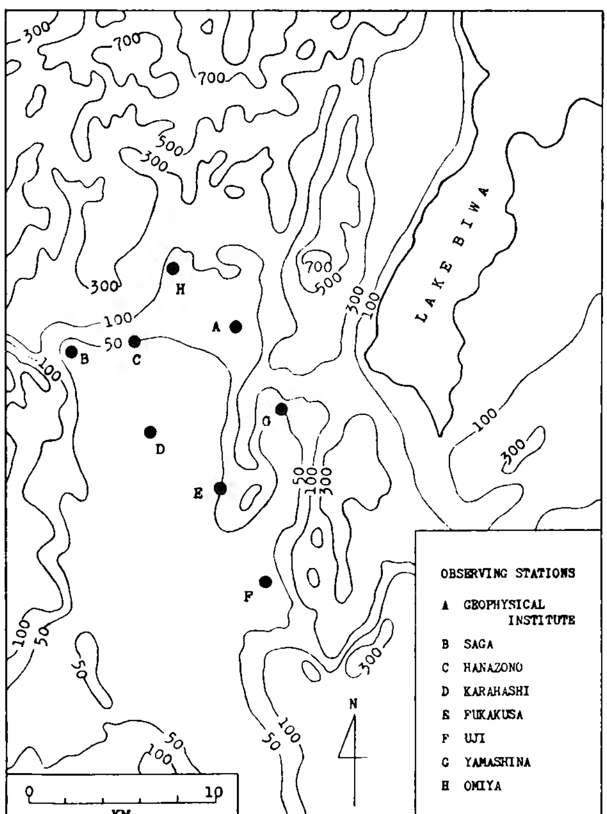

Fig. 1 Topographical map (height in meter) showing distribution of observing stations.

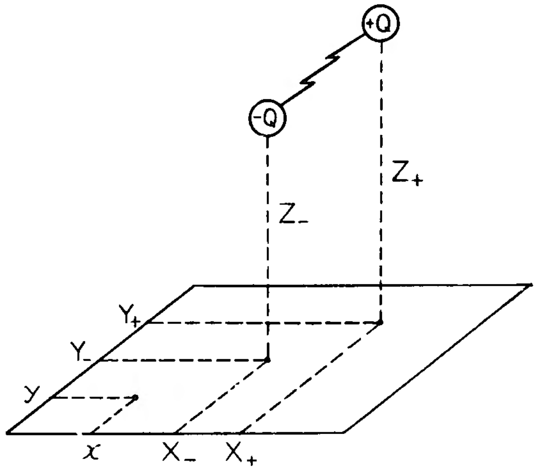

Fig. 2 Coordinate system

was a generating voltmeter type field meter improved in the Geophysical Institute. The primary aim of the observation was to find the locations of charge center and magnitudes of charge taking part in intra-cloud and cloud-ground discharges. The network method was used for the first time by Workman, Holzer and Pelsor (1942). The theory of the method can be explained by reference to Fig. 2. Assume that the surface of the earth is an infinite conducting plane, and that lightning discharges involve the neutralization of spherical charge center. Then the disappearance of two charge centers $+Q$ and $-Q$ whose positions are (X_+, Y_+, Z_+) and (X_-, Y_-, Z_-) respectively, produces an electric field change ΔF at the surface point (x, y), such that

$$\Delta F=\frac{2QZ_-}{[(X_--x)^2+(Y_--y)^2+Z_-^2]^{3/2}}-\frac{2QZ_+}{[(X_+-x)^2+(Y_+-y)^2+Z_+^2]^{3/2}} \qquad (1)$$

To determine the seven unknowns, a set of seven equations is necessary. Therefore, the electric field change must be measured at least at seven points on the plane. In the case of a cloud-ground discharge which is equivalent to the neutralization of monopole in a cloud and its image, the four unknowns appear and the right hand of the equation is reduced to a single term, hence four stations at least need. The method has the advantage that one can ignore the complicated field pattern of a thunderstorm and deal only with the charge center taking part in a lightning discharge. However, the analytical solution of the seven simultaneous equations as the above-mentioned is impracticable. In practice, the data were analyzed by the means particular to the authors as Workman, Holzer and Pelsor (1944) and Reynolds and Neill (1955). In the present study the analysis has been made by comparing the results of the observation with samples of map of field distribution due to the neutralizations of monopole and dipole. Here, dipole is the extreme case of two charge centers, positive and nagative, whose separation becomes very close, but the electric moment remains the same with that of the two charge centers. A dipole is in general determined by six quantities, that is, three coordinates of its position, two direction cosines of its axis and strength of its moment. Thus, substituting the dipole for two poles, the analysis becomes rather easy. But the height of dipole is merely the mean height of positive and negative charge centers, which may be regarded as the level of charge separation. In the case of monopole neutralization, though the solution can be obtained by the analytical calculation, the above method is more practicable than the calculation. Considerable sets of field changes do not give any definite results by the analysis. It suggests that such data are probably due to more complicated discharges than the spherical charge neutralizations which are assumed in the theory of network method.

On September 11, 1958, a violent thunderstorm attacked the network. At 15^h00^m, the storm appeared in NE direction from the network, and during 15^h30^m -17^h30^m the center of the storm passed across the network to SSE direction. The maximum frequency of lightning discharges which were counted by a sudden change of field, about 30 in 5 minutes, occurred at about 16^h00^m. Out of more than 350 discharge records, 86 data which seemed to be possible to analyze were selected. The analysis gave definite results for 47 cases as a monopole neutralization, 6 cases as a dipole neutralization and did not give any definite result for 33 cases. The results are shown in the following table. The discharge number in the table is the order of occurrence. Since the discharges were selected as nearly, uniformly distributed through the whole storm time, the results of analysis were considered as a feature of the storm as a whole, but not of particular epoch. The number of dipole neutralization analyzed here was much smaller than that of monopole neutralization. It suggests that a number of intra-cloud discharges could not be analyzed as the dipole neutralization.

It is noted that, among 47 monopole discharges in the table, for 30 discharges, heights of monopole are fouud as 10 or 11 km, which is extraordinarily higher value, and their magnitudes range between 1.5 and 10 coulumbs, while in the other 17 discharges, heights of monopole are less than 10 km and the lowest value is 3 km. It is also noted that, as a whole, the larger height is found in the earlier stage of the storm and the smaller height in the later stage of the storm. In the other storms observed in 1958, there was no case of neutralization of monopole whose center was 10 km or more. In the storms observed in 1957, only

Table. Magnitudes of Charge and Moment, their Heights for Monopole and Dipole neutralized by a Discharge. (Thunderstorm on September 11, 1958)

Discharge No.	Monopole Charge Coul.	Monopole Height Km	Discharge No.	Monopole Charge Coul.	Monopole Height Km	Dipole Moment Coul. Km	Dipole Height Km	Cot θ
1	−1.5	11	26	−10	11			
2	−6	9	27	−5	10			
3	−9	11	28	−3	10			
4	−1.5	11	29	−2.5	11			
5	−1.5	11	30	−6	10			
6	−1.5	11	31	−7	11			
7	−2.5	11	32	−10	11			
8	−2	10	33	−2	9			
9	−2	9.5	34	−10	11			
10	−2	9	35	−7	10			
11	−5.5	11	36	−2	11			
12	−3	11	37	−5.5	11			
13	−6	11	38	−3	9.5			
14	−4	11	39	−5.5	11			
15	−8	11	40	−1.5	7.5			
16	−6	11	41	−3	8			
17	−4	11	42			10	5.5	0.2
18	−3	6.5	43			−7	4.5	0.4
19	−3	8	44	−2	3			
20	−5	11	45	−4	3			
21	−9	11	46	−6	4			
22	−10	11	47	−3	5			
23	−2	8	48			38	7	0.4
24	−5	9	49			13	7	0.3
25	−4.5	11	50			9	7	0.2
			51			−21	7	0.2
			52	−6	4			
			53	−6	4			

Moment of dipole is counted as positive when it has positive vertical component. θ is inclination of dipole to the ground.

one case of monopole neutralization of −6.4 coul. at the height of 11 km, was found in the early stage of the storm on August 4. Fig. 3 is an example of distribution of field change over the network represented by the neutralization of a negative charge center.

As for the summer thunderstorm in Japan, Kitagawa and Kobayashi (1958) pointed out that the negative charge taking part in a cloud-ground discharge distributed in a columnar region nearly vertical in a cloud, in accordance with the finding by Malan and Schonland (1951) for the thunderstorm in South Africa. As far as the electric field intensity at the observing station is concerned, the electric field distribution by a point charge in Fig. 3 is fairly well represented by a vertical line distribution of uniform charge density whose lower and upper ends are 4 and 18 km respectively, and has the same projection point on the ground with that of

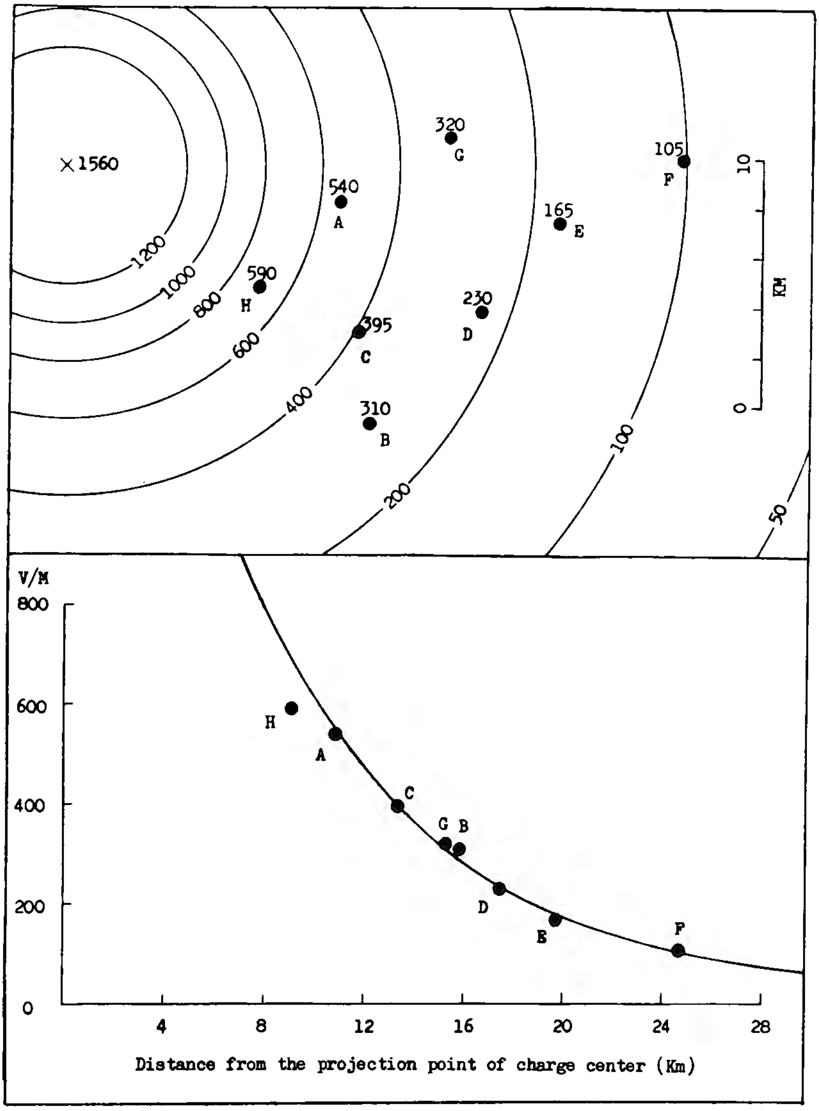

Fig. 3 Electric field changes due to discharge no. 26 thunderstorm, on Sept. 11, 1958.
upper: observed values (v/m) and model distribution caused by neutralization of negative charge 10.5 coul. at 11 km above ground.
lower: observed values (v/m) and distance-electric field curve of the model.

the point charge, but the total charge is 1.1 times the point charge. It is, however, hard to understand that the negative charge taking part in a cloud-ground discharge extends up to such high altitude as 18 km. It is also difficult to interpret the observed field changes as the results of a discharge between the negative charge at the high altitude in the cloud and the positive space charge outside the cloud top, because such a discharge has a bipolar character of positive polarity which produces a negative field change at the remote distance from the projection point of discharge. The radius R of circle at which the field change reverses its sign, is expressed by

$$R=\left(2+\frac{9}{4}\cot^2\theta\right)^{1/2}Z \qquad (2)$$

where Z is the height of dipole and θ the inclination of dipole. If $\theta=90°$, then, $R=\sqrt{2}Z$ and say $Z=11$ km, then $R=16$ km, even if $\theta=45°$, $R\simeq23$ km for $Z=11$ km. While, in Fig. 3, at the place of 24 km from the projection point of dipole, the field change is still larger than 100 v/m. However, so far as the net field change concerns, it may be possible to suppose that the field change is due to a discharge of negative charge in the upper part of cloud to the conducting upper atmosphere. Because the field change is definite by disappearance of charge through the lightning either to the ground or to the conducting upper atmosphere. The difference between these two kinds of discharges can be found by means of a fluxmeter of quicker response than a field meter used here, or in favorable conditions by still photographs and eye observations of lightning. The air temperature at the height of 11 km is $-42°$C at the storm time. The temperature is deduced from the data at Yonago (about 230 km, WNW from Kyoto), Shionomisaki (about 180 km, South from Kyoto) and Wazima (about 290 km, NNE from Kyoto) in Aerological Data of Japan (September, 1958) published by Japan Meteorological Agency, as the mean of three stations' values interpolated for the time from the data at 9^h and 21^h respectively of each station.

Marshall (1953) found, by the observation of radar echos, that lightnings occurred at the height where the most probable temperature was $-40°$C. Also, Atlas (1958) found that the radar echos came from lightnings at the height higher than 12 km. These high locations of lightnings suggest that lightning discharges between the cloud top and the conducting upper atmosphere may occur not infrequently. Tamura (1960) found that the center of negative charge taking part in a cloud-ground discharge was higher in the early stage than in the later stage of the storm, and suggested that the upper part of the cloud is negatively charged in the front and positively charged in the rear of the cloud top. The evidence described here is accordant with the suggestion, but the negative charge seems so intense and high as a lightning discharge takes place toward the conducting upper atmosphere instead of toward the earth. In such a case, the negative charge will be transferred to the conducting upper atmosphere by a lightning discharge and through the atmosphere upside of the cloud the gradual conduction current will be found between the front and rear parts of the cloud top. If the positive charge in the rear part of the cloud top is small, then by the gradual conduction current, the negative charge will be transferred mostly toward the conducting upper atmosphere. Gish and Wait (1950) and Stergis, Rein and Kangas (1957) found that there was a positive current flowing upward from the top of the thunderstorm toward the conducting upper atmosphere. This current is in the right direction and of the order of magnitude required for the hypothesis by Wilson (1920) that thunderstorms are the generators which supply the electric current necessary for maintaining the earth's negative charge. The present evidence, however, shows that, at least in the early stage of thunderstorm, the current is in the direction opposing to the Wilson's hypothesis.

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